

Precipitation on the valley floor and the surrounding mountains in the form of rain and snow is the source of recharge to the ground-water system. Streams crossing the valley lose significant quantities of water to the underlying material. Deep percolation of irrigation water (some of which is diverted from the Missouri River) and leakage from irrigation canals provide significant recharge during the irrigation season. Recharge from irrigation of lawns and from effluent of septic tanks also contributes to the ground-water supply, but this source is relatively minor.

Ground water moves generally toward Lake Helena (fig. 1), which is the natural point of ground-water discharge for the valley (Wilke and Coffin, 1973). Numerous domestic, stock, and irrigation wells located throughout the valley intercept part of the flow. Evapotranspiration, particularly in the north-eastern part of the valley where ground-water levels are persistently high, accounts for a significant amount of water loss from the ground-water system.

Depth to ground water

Sewage effluent discharged from properly constructed septic tanks and soil-absorption systems should pass through a zone of unsaturated soil before entering the underlying saturated ground-water system. The oxygen present in the unsaturated zone provides some degree of protection to the ground-water system by oxidizing or decomposing some of the constituents in the sewage effluent. Health authorities commonly accept a minimum thickness of 4 feet of unsaturated material to obtain the optimum benefit of oxidation and decomposition. Because soil-absorption systems are commonly buried 2 feet below land surface, the City-County Health Department requires a minimum of 6 feet from land surface to the saturated zone for approval of a septic tank soil-absorption system (Will Selser, County Sanitarian, oral commun., 1979).

Although the approximate depth to ground water is known throughout the valley, the specific areas where the depth to ground water is less than 6 feet are difficult to delineate. The depth to ground water is often assumed to be the depth to water measured in wells. However, under confined (artesian) conditions, the depth to water in a well does not coincide with the depth to ground water.

Under confined conditions, an aquifer is overlain by a layer of material having less permeability than the aquifer. The water level in a well perforated in a confined aquifer stands at a level higher than the top of the aquifer. The water level in this instance coincides with the hydrostatic pressure level (potentiometric surface) in the aquifer. Conversely, water percolating from above may be trapped (perched) above the less permeable layer, in which instance the water level in a shallow well could be different than in a well completed in the confined aquifer.

Under unconfined conditions, significant confining layers are absent. In this instance, the water level in a shallow well that just penetrates the ground-water body coincides with the top of the water table. The water level in deeper wells may be higher or lower than in a shallower well depending upon whether

the well is located in a discharge or recharge area.

Thus, water levels in the shallowest wells will provide the most accurate data to determine the depth to the saturated zone. In the absence of shallow wells, water-level measurements from deeper wells may be useful if the well construction is known and the hydrologic conditions are understood.

When one attempts to define a precise depth to water, for example a minimum of 6 feet for approving a septic system, the uncertainties involved need to be considered. Neither the land surface nor the water table are uniform in slope. Land-surface contours on U.S. Geological Survey 15-minute topographic maps of the valley have an interval of 40 feet. Between contours, an elevated or depressed area of as much as 40 feet may be present, but not be shown on the maps. Relief of this magnitude does not occur in the valley, but numerous areas with less relief such as old streambed channels do occur.

Local recharge and discharge patterns complicate the configuration of the water table. Irrigation ditches, for example, produce recharge mounds that persist through the irrigation season. Flood irrigation on croplands causes transient mounds that dissipate between flooding cycles. Drainage ditches in the low-lying parts of the valley artificially depress the water table. Pumping of large-capacity irrigation wells causes a local depression of water levels.

To refine earlier maps showing depth to water (Wilke and Johnson, 1978), water levels in test wells drilled during this project were measured periodically. Although these measurements provide additional control for estimating depth to water, the control is still limited to a finite number of data points. Where the depth to water is about 6 feet, hydrologic test pits are the best means for determining the precise depth to water at a specific site. The approximate minimum depth to water throughout the valley during 1976-79 is shown on plate 1. Although the map needs to be used with caution because of the uncertainties outlined above, it will be useful in determining the need for on-site test pits.

Water levels fluctuate seasonally in response to recharge. Hydrographs that show the water-level fluctuations in selected test wells for various areas of the valley are included on plate 1. The hydrographs illustrate both the magnitude and the timing of fluctuations. This information can be useful in evaluating water-level information from on-site test pits. By comparing a water level from a test pit with a hydrograph from a nearby test well, prediction of the seasonal high water level should be possible without requiring a full cycle of data. These hydrographs show only one season of fluctuation. During wetter or dryer years, the seasonal fluctuation may be more or less than during 1978-79.

Near the margins of the valley, the depth to water fluctuates seasonally as much as 15 feet. In lower lying areas, water levels fluctuate as little as 2 feet. The period of highest water level is directly related to the source of recharge. Water levels in most wells in the valley are highest in July or August in response to surface-water irrigation, but water levels in a few

wells located near stream channels are highest during spring runoff. During the spring of 1975, excessive runoff caused widespread flooding in the valley and subsequent recharge to the water table. Flooded basements accompanied the unusually high water-table conditions resulting from this excessive runoff.

Distribution of fine-grained material

Helena Valley residents have long placed faith in the supposed existence of a continuous layer of fine-grained material that protects deeper aquifers from pollution by septic-tank effluent. Most wells in the Helena Valley penetrate varying thicknesses of silt and clay below the local water table, but above the sand and gravel aquifers in which the wells are completed. This "clay layer" or "hardpan" has been assumed to be an impermeable barrier through which sewage effluent or other pollutants could not pass.

The alluvial-type depositional history of the heterogeneous unconsolidated material makes the existence of an extensive and continuous layer of fine-grained material unlikely. Results of earth-resistivity surveys by Layne-Minnesota Co. and lithologic logs for three test wells drilled for the City of Helena in the southern part of the valley (R. A. Nisbet, City of Helena, written commun., 1979) indicate that relatively impermeable clay layers in the unconsolidated material are variable in thickness and extent. Furthermore, even the most fine-grained materials have some degree of permeability that would permit vertical migration of ground water under certain hydraulic-head conditions. Thus, there is little validity to the widespread belief that water from wells drilled to "second water" cannot be polluted.

If an extensive and continuous layer of fine-grained material underlies the valley, its presence should be evident from records of water wells. Drillers generally keep a record of the materials penetrated in drilling wells (well log), but the inconsistency of drillers' descriptions of materials makes interpretations difficult. What one driller might record as silty sand might be called clay, silty clay, or dirty sand by other drillers. The detail with which the record is kept, the type of drill used, and the driller's personal description of various lithologic units all contribute to inconsistency between logs. As a result, correlation of individual layers from one location to another on the basis of drillers' logs alone is tenuous.

To supplement the drillers' logs, about 60 gamma-ray geophysical logs were run in the test wells drilled during this study and in a few existing water wells and test holes. A gamma-ray log records the natural gamma radiation of the materials surrounding the well bore. Generally, in alluvial deposits, the primary source of natural gamma radiation is the radioactive isotope of potassium, potassium-40. During the weathering process, potassium-rich minerals are reduced to clay. The clay-rich deposits normally contain greater percentages of potassium than the adjacent sands or gravels and, consequently, emit more gamma radiation. A gamma-ray log can thus be used to distinguish between the fine-grained and coarse-grained layers.

More than 1,000 test borings were made by the U.S. Water and Power Resources Service (formerly U.S. Bureau of Reclamation) from 1949 to 1977 as part of a Helena Valley drainage investigation. Detailed, but unpublished, descriptions by geologists and soil scientists of the penetrated deposits were a valuable source of information defining the occurrence of fine-grained material at shallow depth. For their work, a zone was considered a barrier to percolation if the permeability was less than 20 percent of the weighted permeability of the materials above the zone (Glen Sanders, U.S. Water and Power Resources Service, oral commun., 1979). Most of the borings were less than 20 feet deep and located where potential drainage problems caused by shallow and relatively impermeable layers were anticipated. In general, those were areas where few people lived and for which no additional subsurface information was available.

The data obtained from drillers' logs of water wells, the drainage investigation, and the gamma-ray logs are summarized graphically on plate 2. The illustration shows the areas in which the uppermost "impermeable" layer was reported in the depth intervals 0-20 feet, 21-40 feet, 41-60 feet, 61-80 feet, or was absent above the total depth penetrated by the borings. Total depths of wells and test holes that reportedly did not penetrate a significant layer of fine-grained material are included to assist in evaluation of the information.

The illustration shows discontinuities, or "windows," in the fine-grained material through which water could migrate relatively unimpeded into the underlying aquifers. Even within the widespread 0-20-foot zone, the layers of fine-grained material are discontinuous. Because the distribution and quality of the data are not uniform, either laterally or vertically, the boundaries are not sufficiently defined to distinguish between areas suitable or unsuitable for soil-absorption systems.

Two lithologic sections (fig. 3) further illustrate the discontinuous nature of the fine-grained materials. In both sections the upper layers of fine-grained material appear to form fairly extensive lenticular bodies that would retard downward movement of water in the central part of the valley where water levels are normally near the land surface. Around the edges, in the areas of greatest residential development, the layers of fine-grained material are more discontinuous, and appear to represent lenses of relatively impermeable materials within an anisotropic unconfined aquifer. They would retard, but not necessarily prevent, downward movement of polluted shallow ground water into aquifers used for water supply.

AQUIFER TESTS

Aquifer tests were made at five widely spaced sites (pl. 1) during June 6-21, 1979, to obtain data describing the transmissivity and other properties of the aquifers. Observation wells were available for pumped wells 10N03W06ACD01 and 10N03W15DDD01. With the exception of well 10N03W15DDD01, knowledge of the lithology penetrated by the water wells and details of well construction were not available. In addition, the lengths of the aquifer tests were dependent on constraints by well owners and physical problems beyond the control of the investigators. Because of lack of knowledge about the lithology and degree

of penetration of the aquifers by the well casing, and the necessarily short duration of the tests, complete quantitative analysis of the data was not justified. However, the results of the tests provide reasonable estimates of transmissivity as well as evidence that vertical drainage is induced or accelerated by pumping.

One well at each site was pumped for an extended period at a relatively constant rate of discharge. The resulting declines in the water levels in the pumped well and nearby observation wells were recorded at specific times. After the pump was stopped, water levels in the wells were monitored until near total recovery was recorded. The data from the tests are shown in a report by Moreland, Leonard, Reed, Clausen, and Wood (1979).

When a well is pumped at a constant rate, the water level in the pumping well declines as water is removed from the aquifer immediately surrounding the well. As pumping continues, the water levels in nearby wells normally decline, but at a slower rate than in the pumping well. The water surface connecting the wells forms an inverted cone of depression centered on the pumping well. The shape and rate of change of the cone of depression are used to determine the aquifer properties.

The transmissivity of the aquifer is the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Values for each test were obtained by matching the time-drawdown curves plotted from the test data with type curves based on modifications of the original Theis nonequilibrium well formula (Theis, 1935). Most of the time-drawdown curves can be fitted to Theis curves, modified to reflect the effect of recharge or vertical drainage into the pumped aquifer. Best fits were obtained with type curves for nonsteady radial flow in an infinite leaky artesian aquifer after Cooper (1963, pl. 4) or delayed yield for unconfined anisotropic aquifers after Boulton (1963, fig. 1).

The Theis curve is based on the assumptions, among others, that (a) the water-bearing formation is homogeneous and isotropic, (b) the aquifer receives no recharge during the period of the test, and (c) the water removed from storage is discharged instantaneously with lowering of the hydraulic head. Unless these assumptions are met, the time-drawdown curves should not match the Theis type curve. The test results are consistent with the known geohydrology of the area as described above; that is, (a) the water-bearing formation is not uniform in permeability in either the horizontal or vertical direction, (b) recharge from the surface can enter the aquifer during a relatively short period of pumping, and (c) release of water from storage evidently is not instantaneous.

At most sites, the aquifers reacted during the early stages of pumping as would a confined aquifer in which pumpage is replaced almost instantaneously from storage by expansion of the water and compaction of the aquifer. Well-bore storage was negligible after the first minute of pumping. After about 10 to 30 minutes of pumping, the expanding cones of depression evidently intercepted additional sources of water, and drawdown was less than would be predicted from the Theis type curve. Where the source was a recharge boundary such as a

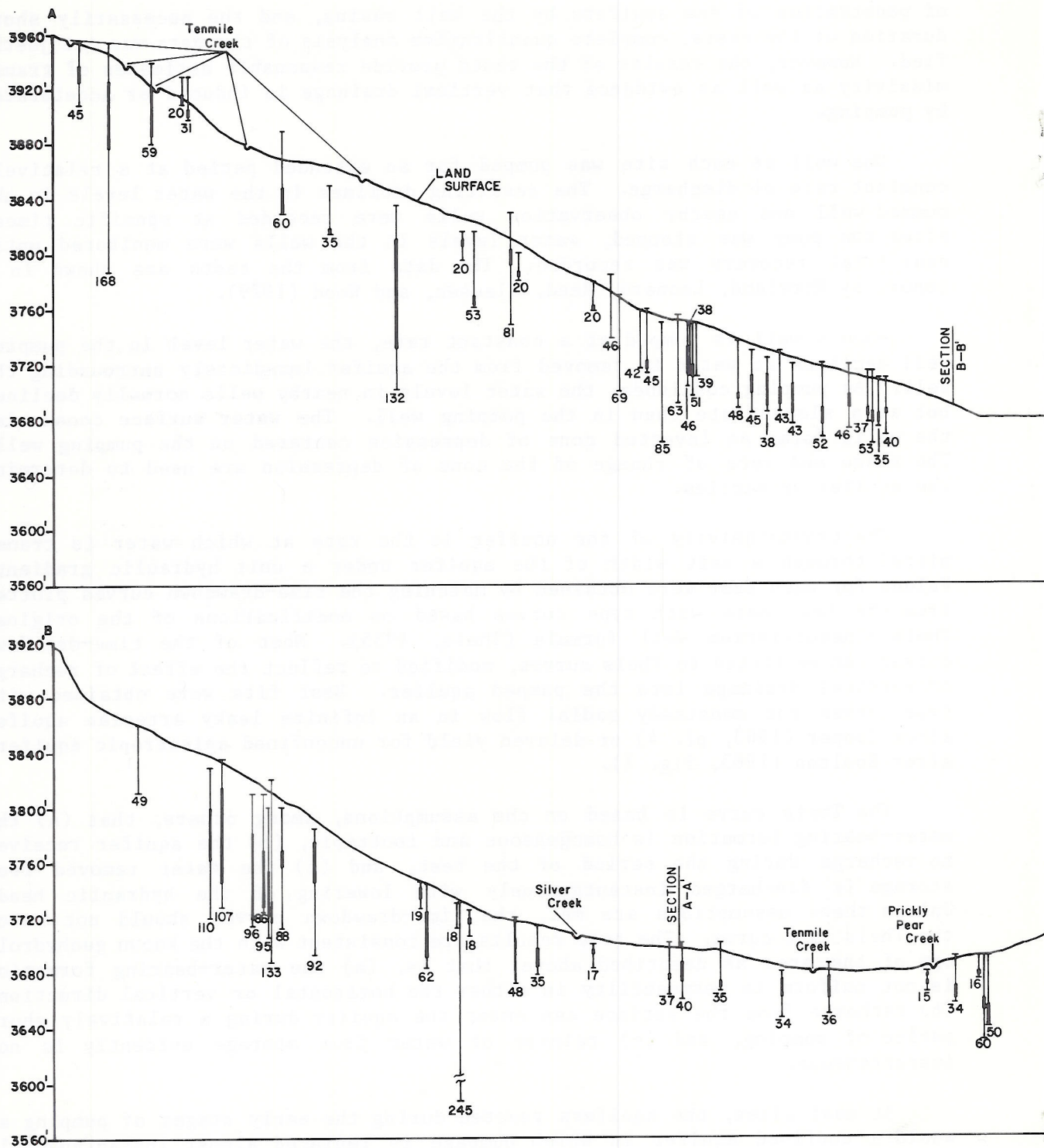
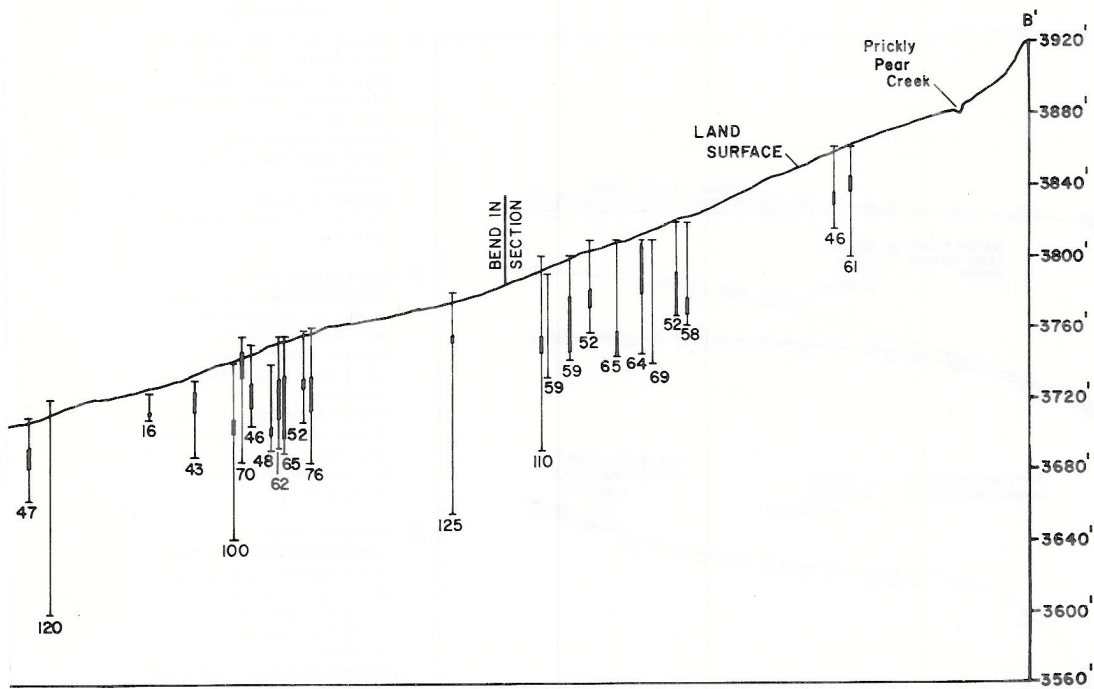
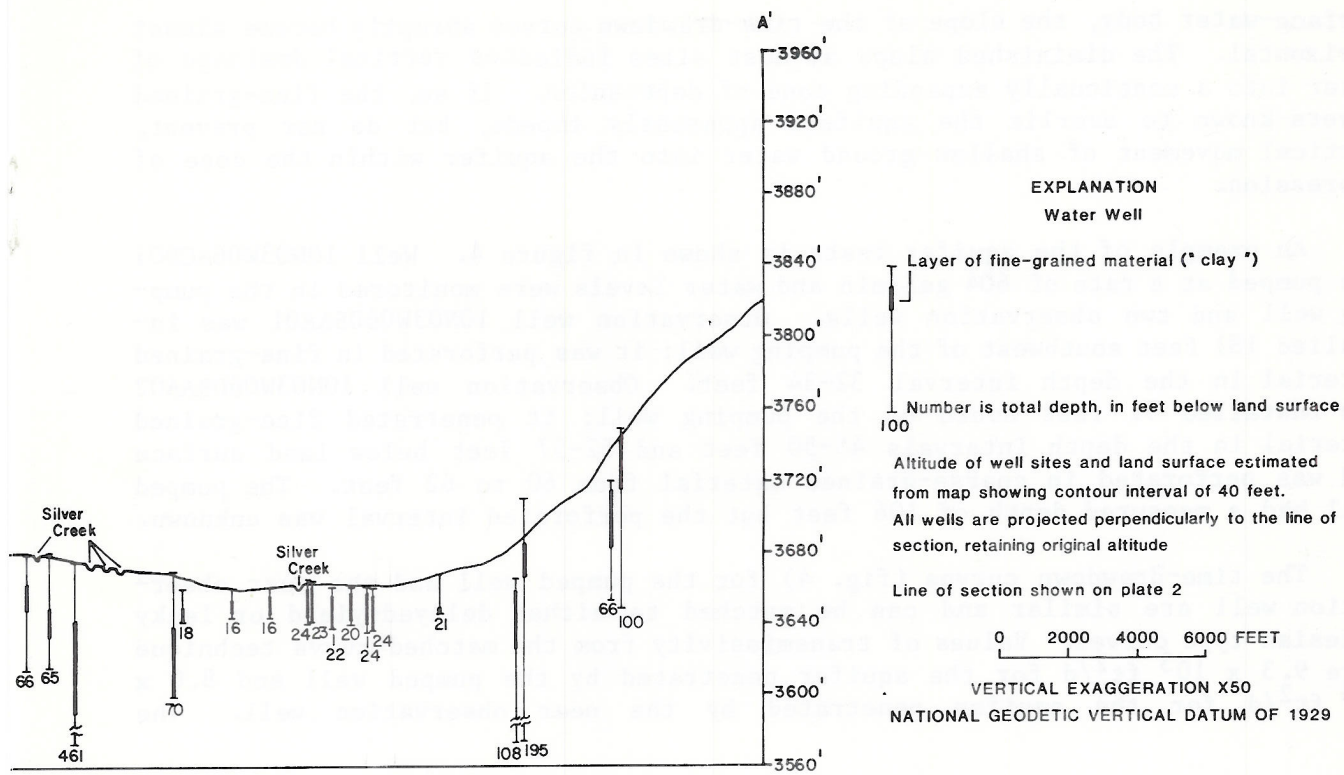


Figure 3.--Sections across Helena Valley showing intervals of fine-grained material ("clay") overlying principal shallow aquifers penetrated by water wells.



surface-water body, the slope of the time-drawdown curves abruptly became almost horizontal. The diminished slope at most sites indicates vertical drainage of water into a continually expanding cone of depression. If so, the fine-grained layers known to overlie the aquifers apparently impede, but do not prevent, vertical movement of shallow ground water into the aquifer within the cone of depression.

An example of the aquifer tests is shown in figure 4. Well 10N03W06ACD01 was pumped at a rate of 604 gal/min and water levels were monitored in the pumping well and two observation wells. Observation well 10N03W06DBAA01 was installed 181 feet southwest of the pumping well; it was perforated in fine-grained material in the depth interval 32-34 feet. Observation well 10N03W06DBAA02 was installed 91 feet south of the pumping well; it penetrated fine-grained material in the depth intervals 45-50 feet and 52-57 feet below land surface and was perforated in coarse-grained material from 60 to 62 feet. The pumped well had a measured depth of 106 feet but the perforated interval was unknown.

The time-drawdown curves (fig. 4) for the pumped well and the near observation well are similar and can be matched to either delayed-yield or leaky artesian type curves. Values of transmissivity from the matched-curve technique were $9.3 \times 10^3 \text{ ft}^2/\text{d}$ for the aquifer penetrated by the pumped well and $8.0 \times 10^3 \text{ ft}^2/\text{d}$ for the aquifer penetrated by the near observation well. The

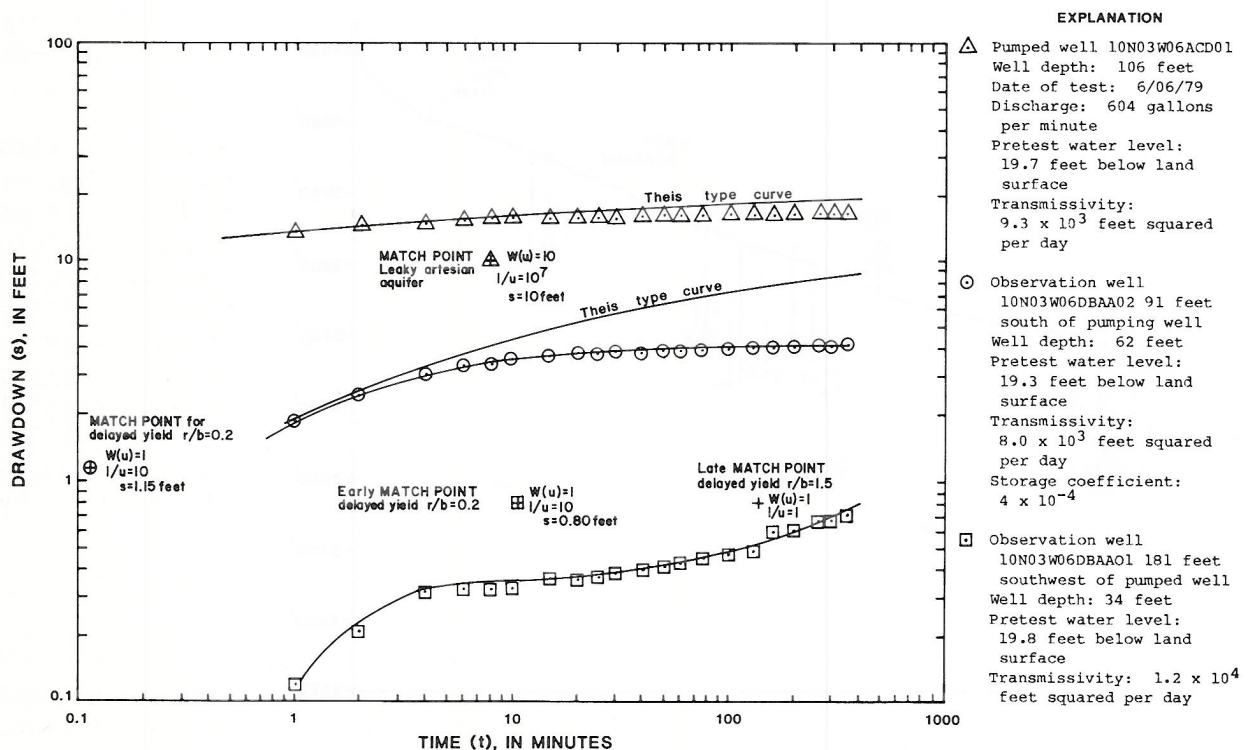


Figure 4.--Drawdown in pumped well 10N03W06ACD01 and observation wells 10N03W06DBAA01 and 10N03W06DBAA02.

coefficient of storage represented by the early phase of pumping was about 4×10^{-4} , within the range expected for a confined aquifer. Drawdown in the far observation well appears to fit a delayed-yield type curve. The drawdown in the far well indicates that downward percolation through the fine-grained material occurs in response to pumping from the underlying aquifer.

A transmissivity of about 1×10^4 ft²/d represents a reasonable estimate for the alluvial aquifer penetrated by three of the pumped wells and is probably appropriate for the aquifer penetrated by most shallow wells in the more densely populated southern part of the valley. It probably is also applicable to estimates of the rate of lateral underflow.

For predicting the long-term effects of pumping on an unconfined or leaky aquifer system, pumping needs to be continued for at least 3 days. During the tests described in this report, none of the wells were pumped for more than 0.5 day. The tests were of sufficient duration, however, to indicate vertical movement of water into the cone of depression created by pumping. For delayed gravity drainage systems, the time-drawdown curve would steepen with extended pumping unless a recharge boundary were intercepted. As the source of gravity drainage is depleted, the time-drawdown curves would again conform to the Theis type curve.

The results of the tests appear to confirm the absence of a continuous, impermeable fine-grained confining layer overlying the alluvial aquifers in the valley. Longer aquifer tests under carefully controlled conditions are needed to more precisely evaluate the probability of delayed gravity drainage into the pumped aquifers.

Relatively large values of transmissivity normally are associated with broad cones of depression centered on the pumping well. Many potential sources of pollution (for example, soil-absorption systems) probably overlie the cones of depression created by pumping of water wells in the valley. Thus, prolonged pumping of wells similar to those tested probably would induce or accelerate vertical drainage of shallow ground water into the aquifers through or around discontinuous layers of fine-grained material. The estimated transmissivity of the unconsolidated material is about 1×10^4 ft²/d. Where the water-table or potentiometric-surface gradient is 20 ft/mi (Wilke and Coffin, 1973), natural underflow through an area 1 mile wide would be 2×10^5 ft³/d or 1,500,000 gal/d. The volume of effluent percolating into the aquifer from above would be much less than this and the effluent would be significantly diluted by underflow water moving laterally toward the well.

QUALITY OF GROUND WATER

Ground water contains dissolved chemicals derived from the rock and soil through which it moves. The amounts and kinds of dissolved chemical constituents depend, in part, on the chemical composition and solubility of the minerals in the rock and soil through which the water moves and the length of time the water is in contact with them. The more soluble the rock material, the more constituents the water can dissolve. Also, the longer the water is in contact with the rocks, the more minerals the water may dissolve.

The primary constituents found in most ground water in the Helena Valley are calcium (Ca^{+2}) and bicarbonate (HCO_3^-). These ions probably result from dissolution of limestone (mainly CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$) common in the bedrock surrounding the valley.

Magnesium (Mg^{+2}) and sulfate (SO_4^{-2}) are the next most common constituents in ground water in the Helena Valley. Magnesium occurs naturally in dolomite and in igneous rocks, both of which occur in the bedrock surrounding the valley. Sulfate commonly is derived from oxidation of pyrite and other sulfides common in the rocks.

Sodium (Na^+), potassium (K^+), and chloride (Cl^-) are the least abundant of the common ions in Helena Valley ground waters. These ions generally are abundant in more arid areas or in areas where sediments accumulated in sea water. Because sodium chloride is very soluble in water, it is readily flushed from the permeable soil and rock.

The relative abundance of the common ions in water samples from each well sampled during this study is shown graphically on plate 3. Calcium and bicarbonate are the predominant ions. The concentration of dissolved solids for most samples is less than 400 mg/L (milligrams per liter). However, the diagrams clearly show that Helena Valley ground waters vary considerably in the types and amounts of dissolved constituents.

If all ground water in the Helena Valley moved through the same rocks along similar paths of flow, all the well waters should be similar in quality. Based strictly on geology and ground-water flow paths, no explanation can be given for the occurrence of radically different water types, as illustrated by the water-quality diagrams on plate 3. Other factors obviously contribute to the water quality.

Many of the apparently anomalous analyses shown on plate 3 can be related to specific sources. For example, samples from several wells in sec. 18, T. 10 N., R. 3 W., contain more than 400 mg/L dissolved solids and have a chemical composition different than samples from most wells in other areas of the valley. This water is thought to contain sewage effluent from the city of Helena that was diverted into the placer mining operations in the Last Chance Gulch gravel deposits to float the dredge. In sec. 17, T. 10 N., R. 3 W., the relatively large concentration (936 mg/L) of dissolved solids in a sample from well 10N03W17ACAD01 probably is related to leaching of sludge and solid waste at the old landfill site near that location. The relatively large concentrations of dissolved solids, sodium, and chloride in samples from wells in sec. 16, T. 10 N., R. 3 W., may be related to leakage from sewage lagoons at the Helena municipal waste-water treatment facility.

At several sites, pairs of test wells were installed to monitor the quality of water in the near-surface aquifer and the underlying aquifers. Analyses of samples from the well pairs in secs. 1, 3, and 17, T. 10 N., R. 3 W., are similar, indicating little if any vertical variation in water quality. In contrast, analyses from pairs in secs. 21 and 30, T. 11 N., R. 3 W., and in sec. 5, T. 10 N., R. 3 W., show larger concentrations of dissolved constituents